Clouds and aerosols radiative effects over West Africa, seasonal and meridional patterns

Olivier Geoffroy, Dominique Bouniol, Françoise Guichard

CNRM-GAME, Météo France & CNRS, Toulouse, France

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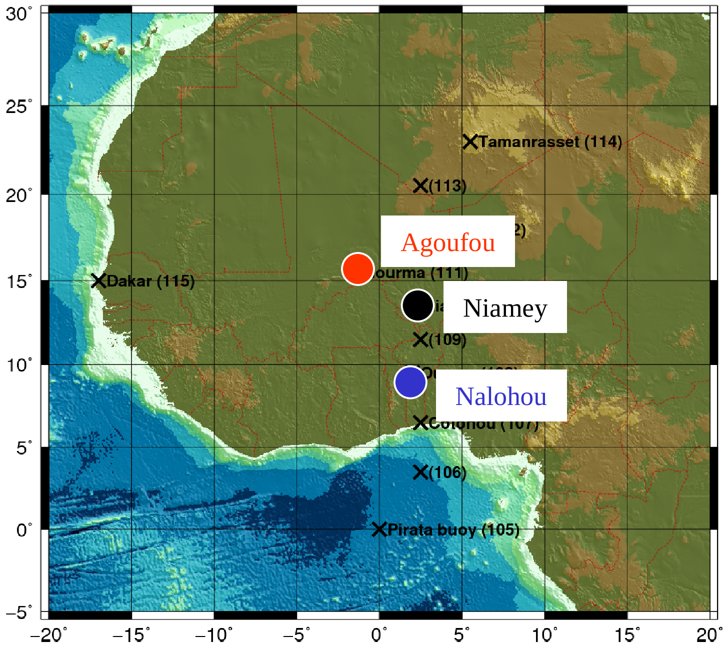
Context and objectives

Clouds = **critical component** of climate models
(Arakawa, 1975; IPCC , 1990, 1995, 2001, 2007)

West Africa specificities:
- Continental zone with **large meridional gradient** in temperature, rain and vegetation.
- **Large annual cycle** of humidity, temperature, aerosols, clouds and rain related to the West African Monsoon.
- Large atmosphere **loading of mineral dust** *(Slingo, 2006)* and biomass burning aerosol.
- **Different cloud types** occur in this region *(Bouniol et al, 2012)*



Objective:

Determination of **CRE and ARE**
(TOA, BOA, atmospheric)

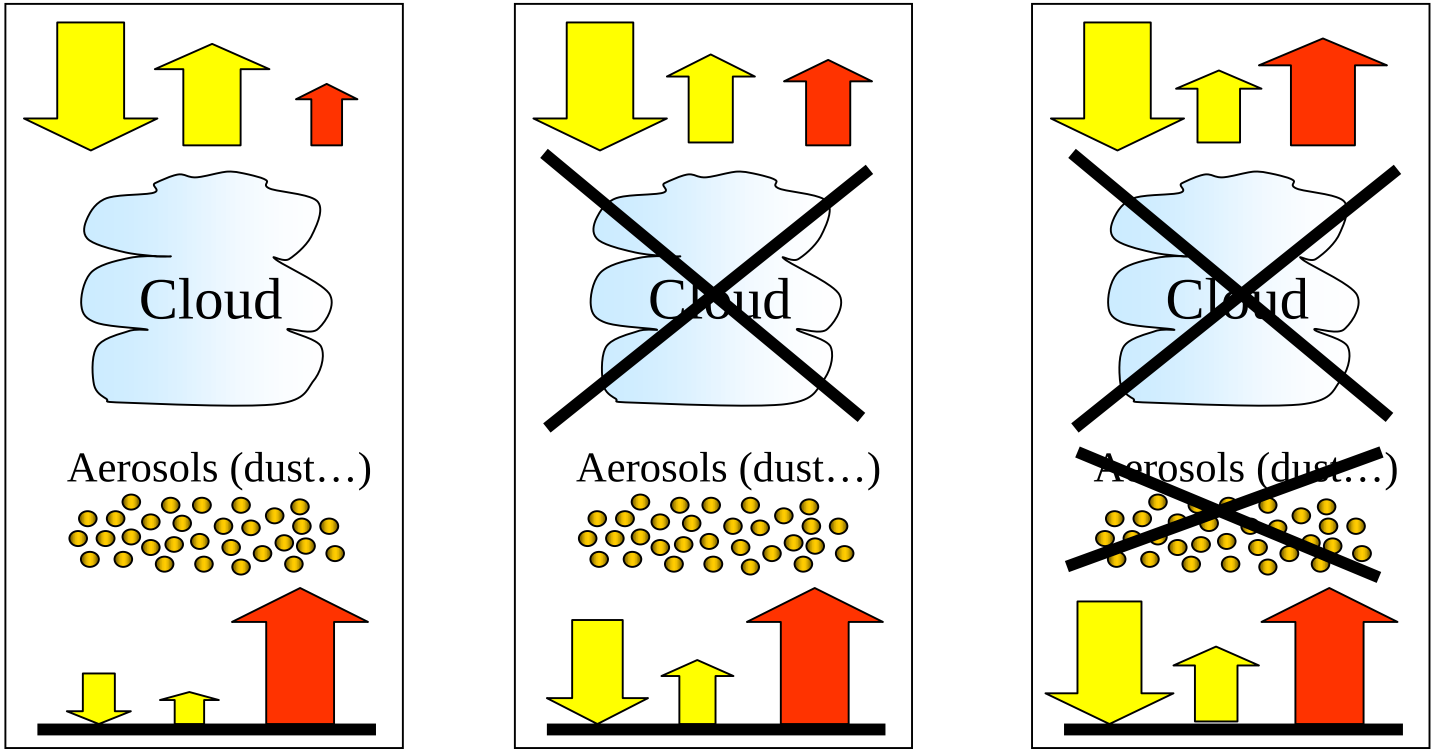
- Over a **meridional transect**
- **Annual cycle**
- CRE of **different cloud types**

→ Identification of main bias in GCMs

Method

CRE (**cloud** radiative effect) = **All-**sky flux - **Clear-**sky flux

ARE (**aerosol** radiative effect) = **Clear-**sky flux - **Clean-**sky flux



Observed | Non-observed | Non-observed

→ use of a **Radiative transfer model** to estimate clear- and clean-sky fluxes

Data and method

Data from AMMA, ARM, AMMA-CATCH

RRTM Inputs

→ Molecular species from RRTM climatology.

→**Humidity** and **temperature profiles**

- **Radiosondes** (Niamey; 4 to 8 per day)
- **ECMWF operational analysis**

(Niamey, Agoufou, Nalohou; 4 per day)

→**Aerosols AOD, SSA, AP** from **AERONET** (1 per hour)

(Holben et al., 2006)

→ Surface albedo from **AMF** (Niamey), **AWS** (Agoufou, Nalohou) or **LSA-SAF** (D. Carrer, C. Meurey)

→ Surface temperature from **AMF, AWS**

Radiative fluxes from RADAGAST, AMMA-CATCH

→ **BOA**

- **AMF** (Niamey, 1-min resolution) *(Slingo et al.,2006; 2009)*
- **AWS** (Agoufou, Nalohou, 15- and 30-min resolution)

→**TOA**

- **GERB** (15-min resolution) *(Harries et al.,2005)*

Cloud masks (Niamey) from radar, lidar from AMF (F. Couvreux)

(*Illingworth et al., 2007; Bouniol et al., 2012*)

INPUTS

Radiative transfert model:

- RRTM LW and SW (AER)

(*Iacono et al, 2008; Morcrette et al, 2008*).

Radiatives fluxes

Clear-sky

Clean-sky

ARE & CRE

(30-minute resolution)

Aerosols

Input SW: SSA, AP and AOD for each **wavelength band**

→ **SSA** and **AP** from AERONET (4 wavelength) and linear interpolation for other wavelength.
→ **AOD** from AERONET, Angstrom coefficient α from AERONET
Extrapolation to **SW** wavelength bands using **Angstrom relationship**,

$$\tau(\lambda) = \tau_0 (\frac{\lambda}{\lambda_0})^{-\alpha} \qquad \lambda_0 = 870 \text{ nm}$$

Input LW: AOD for each **wavelength band**
→ Extrapolation to **LW** wavelength bands using Stanelle et al (2010) **tabulated values** of specific extinction coefficient and SSA:

$$\tau_{abs}(\lambda) = \tau_0 \frac{b_e(\lambda)}{b_{e0}} \frac{1}{1 - SSA(\lambda)} \qquad \lambda_0 = 1020 \text{ nm}$$

→ **Vertical profile** of aerosols:
Redistribution of AOD in each layers by using MACC profiles of aerosol mixing ratio

Plan

1. Method

2. Comparison of modeled / measured clear-sky fluxes

3. ARE and CRE annual cycle, meridional transect

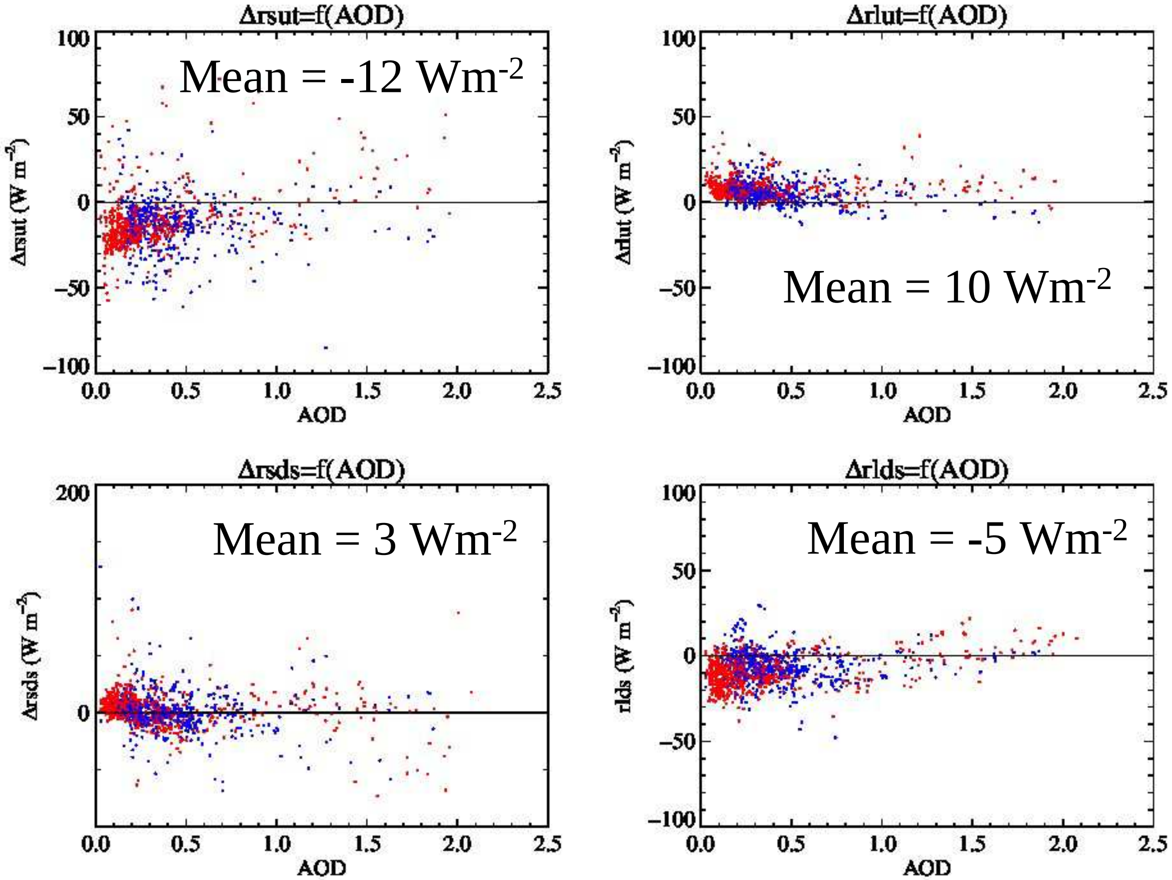
4. Contribution of the different cloud types

RRTM-Observation, clear-sky

SW LW

TOA

BOA



Niamey

IWP < 30 kg m^{-2}
IWP > 30 kg m^{-2}

- Larger differences at TOA (SW). With local albedo, TOA SW bias ~ 30 Wm^{-2}
- Larger bias for small AOD and low IWP. Underestimation of AOD ?
- Similar results in Agoufou, larger differences in Nalohou at BOA
- Bias SW TOA and LW → opposite sign

Plan

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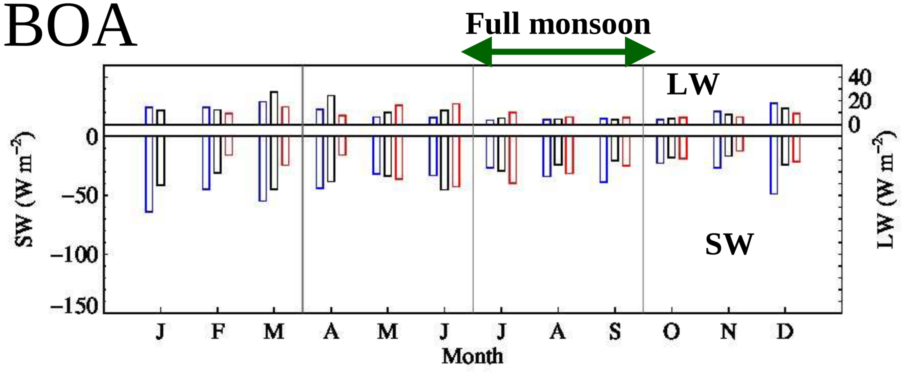
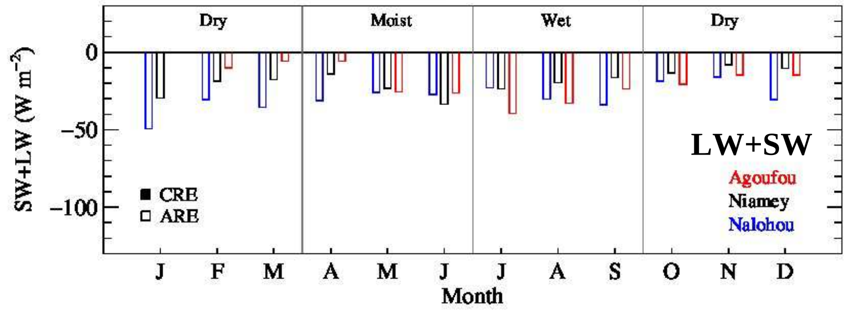
3. ARE and CRE annual cycle, meridional transect
- BOA
- TOA
- atmospheric

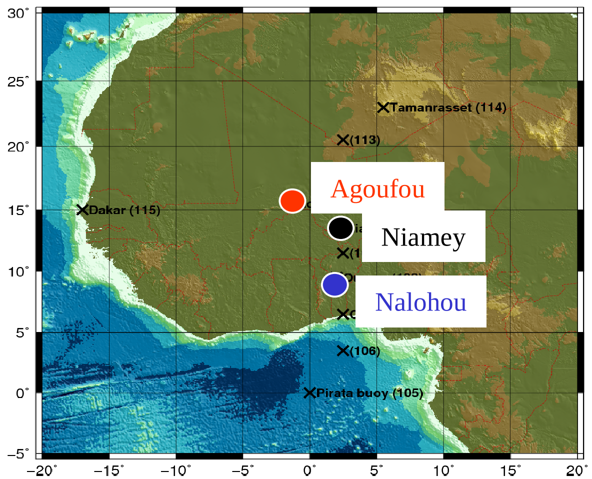
4. Contribution of the different cloud types

ARE & CRE annual cycle - transect

BOA



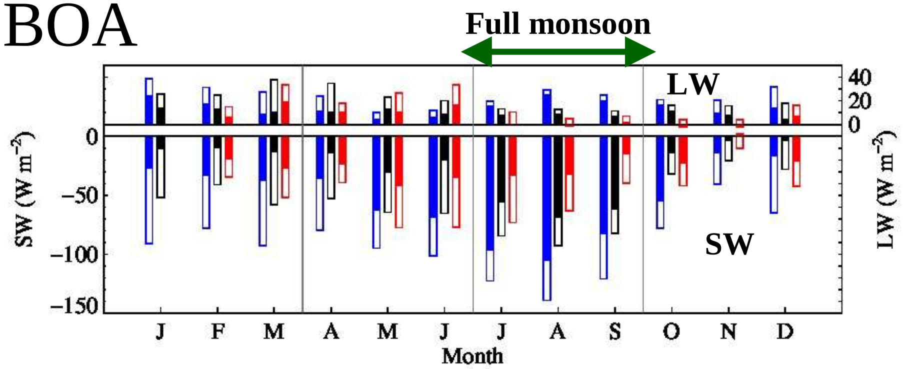


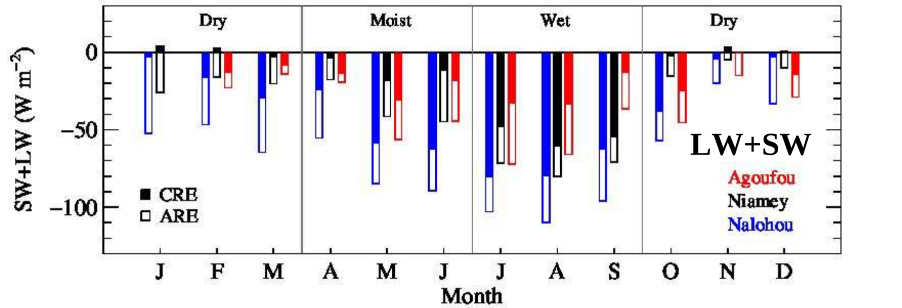


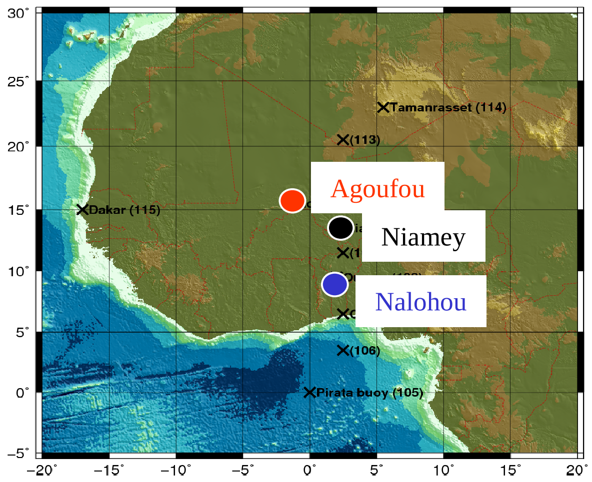
ARE BOA
- Larger ARE in the SW. Cooling of the surface
- Net BOA ARE in the dry season consistent with McFarlane et al (2009)

ARE & CRE annual cycle - transect

BOA



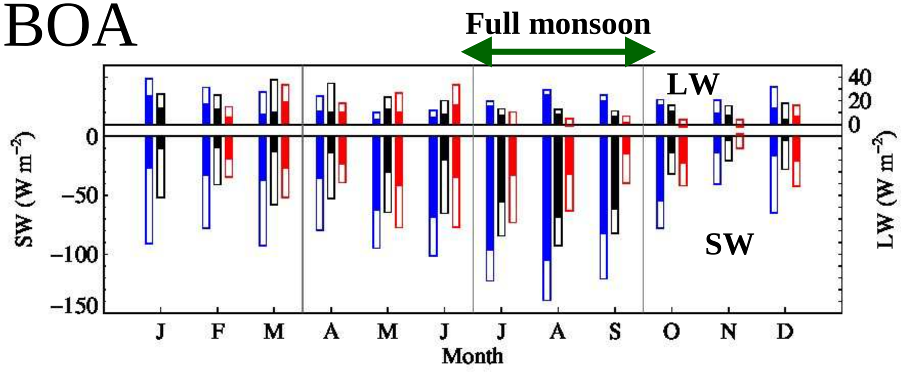




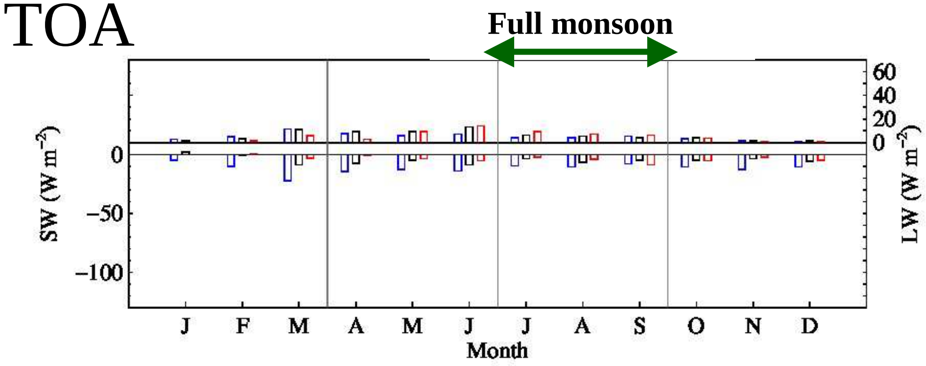
CRE BOA
- SW: Large annual cycle. Southward gradient.
- LW: Lower in JAS (Water vapor masking). LW < SW

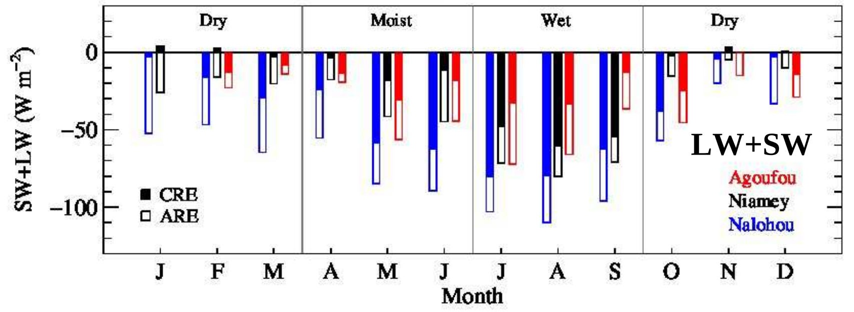
ARE & CRE annual cycle - transect

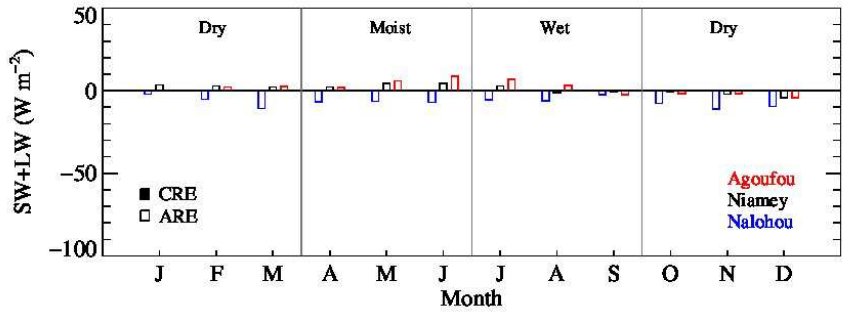
BOA

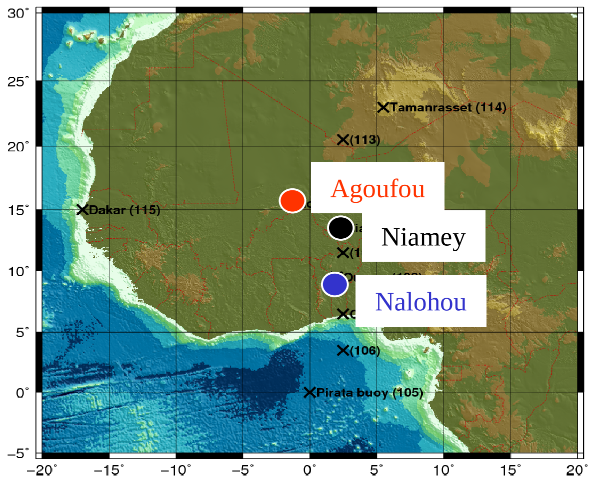


TOA





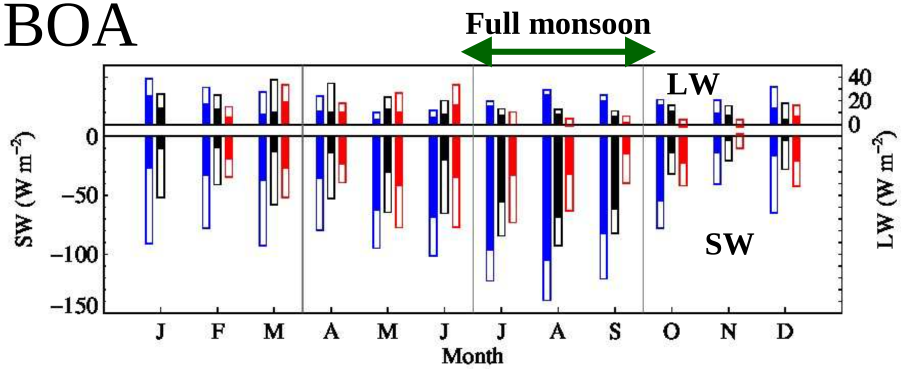




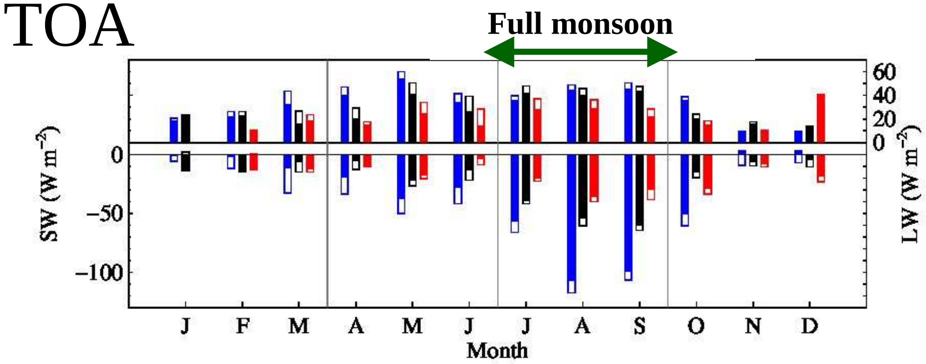
ARE TOA
- Relative amplitude LW ~ SW
- Small total effect

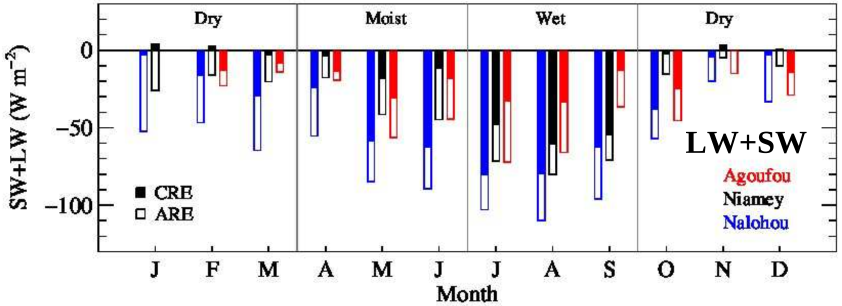
ARE & CRE annual cycle - transect

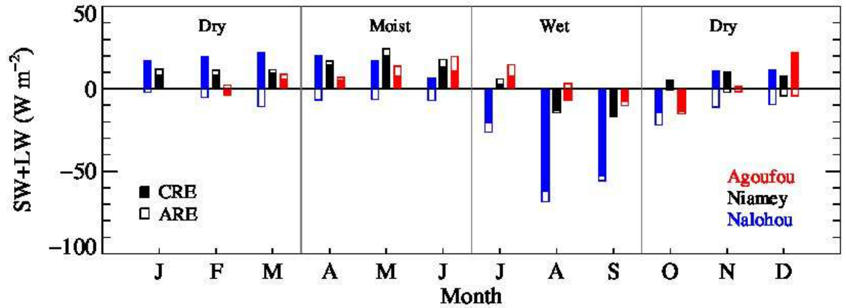
BOA

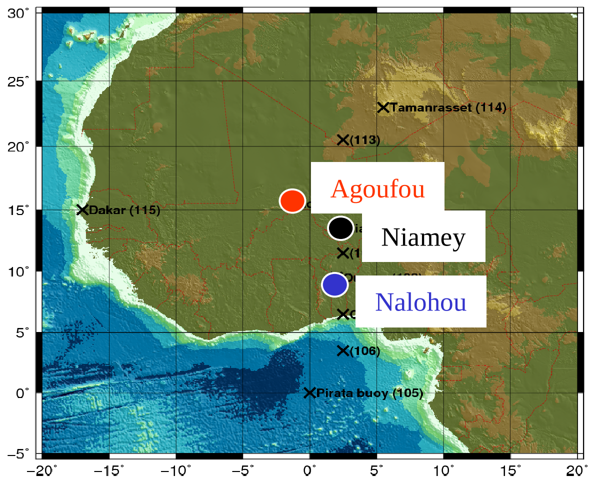


TOA







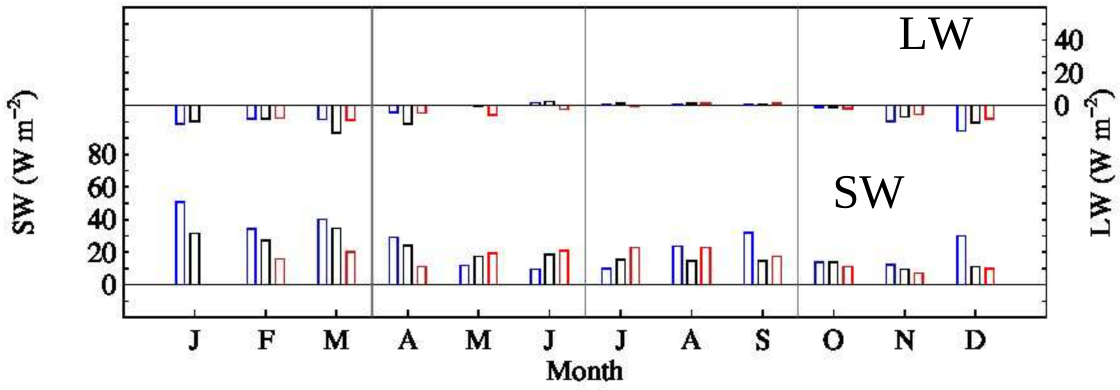


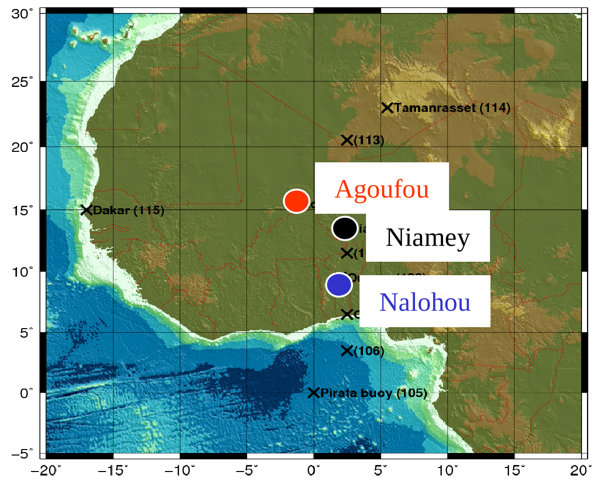
CRE TOA
- SW dominates southward during the monsoon
- LW dominates northward and in the dry season
- JAS pattern consistent with CERES-EBAF 1978-2008 mean (Roehrig et al., 2013).

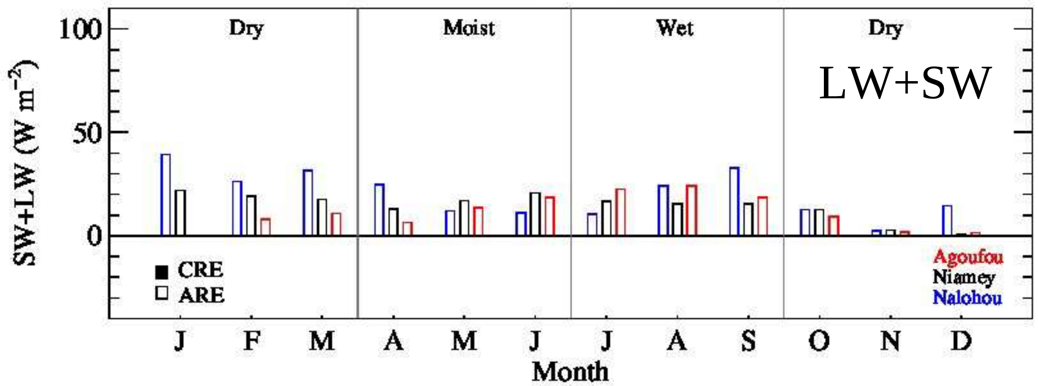
ARE & CRE annual cycle - transect

Atmospheric (= TOA net - BOA net)

Positiv sign = warming





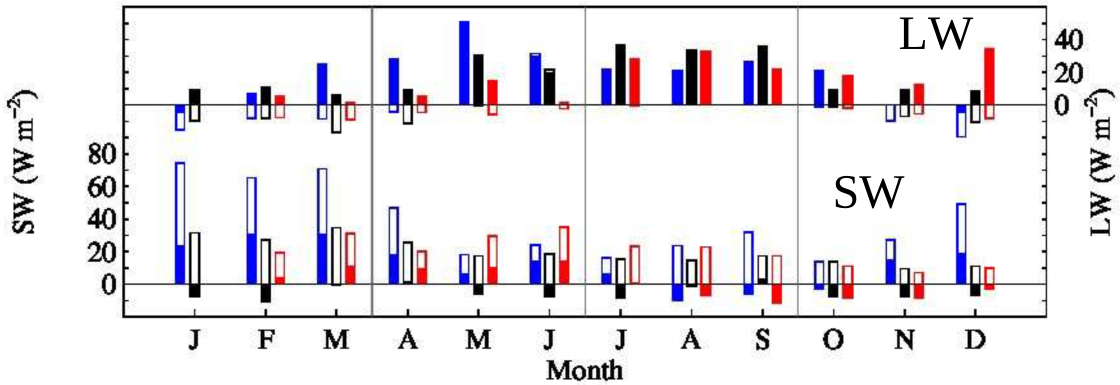


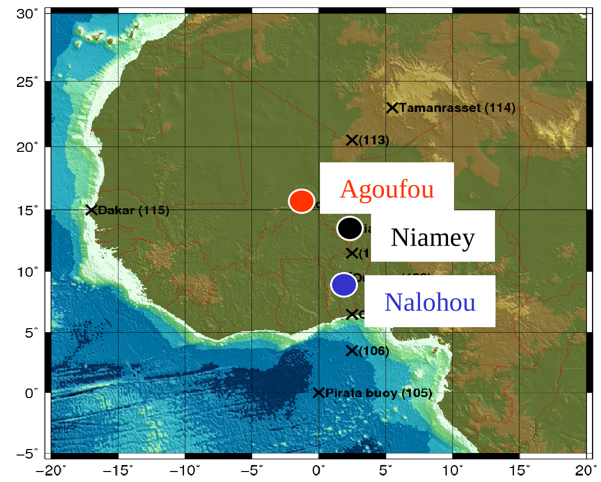
ARE atmospheric
- LW small effect. Cooling
- SW warming. Larger during the monsoon except in Nalohou
- LW+ SW: warming

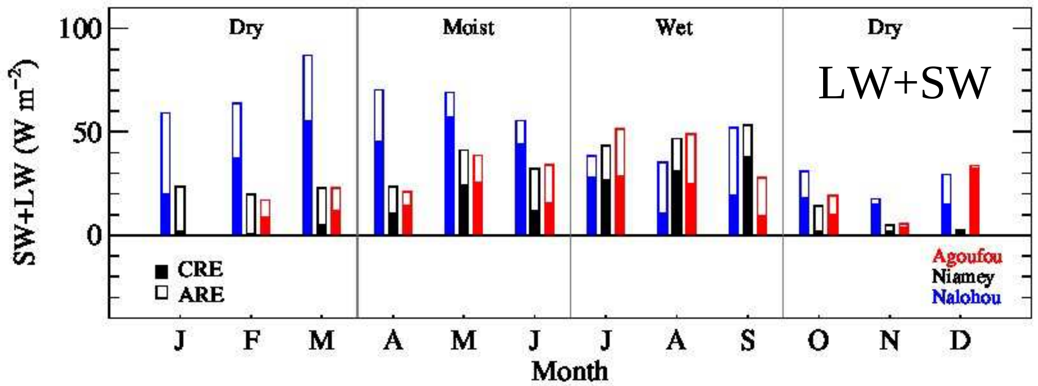
ARE & CRE annual cycle - transect

Atmospheric (= TOA net - BOA net)

Positiv sign = warming







CRE atmospheric
- LW: warming effect (larger relative TOA CRE than TOA ARE)
- SW: small effect
- Large amplitude in the dry season in Nalohou due to clear-sky bias ?
- SW+ LW: warming. Large during the monsoon.

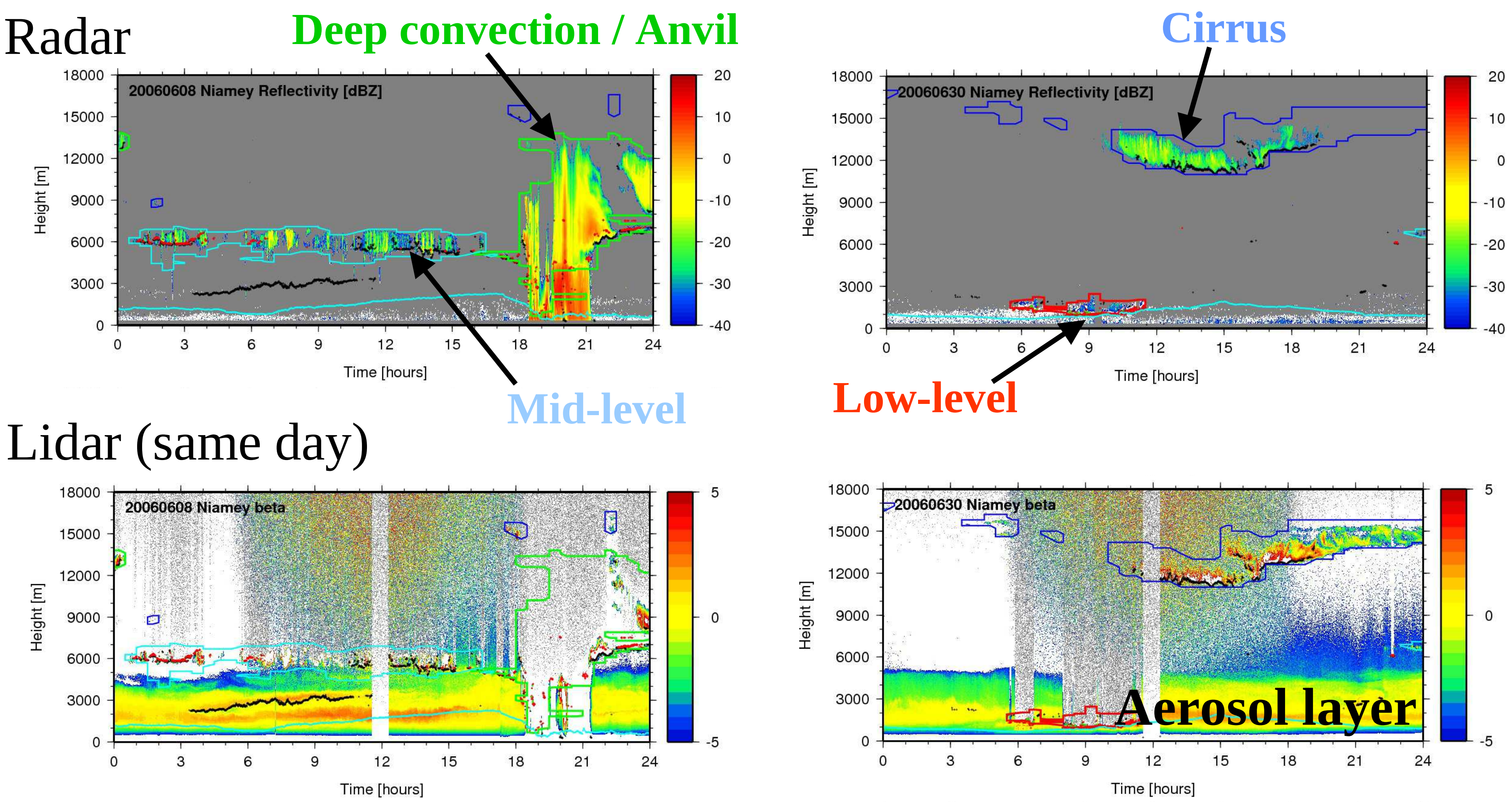
- Comparison with Miller et al. (2012):
Similar annual cycle but magnitude differ.
e.g. CRE+ARE atmospheric 30 Wm^{-2} lower
- ↘ differences with GCM

Plan

1. Method
2. Comparison of modeled / measured clear-sky fluxes
3. ARE and CRE annual cycle, meridional transect
4. Contribution of the different cloud types

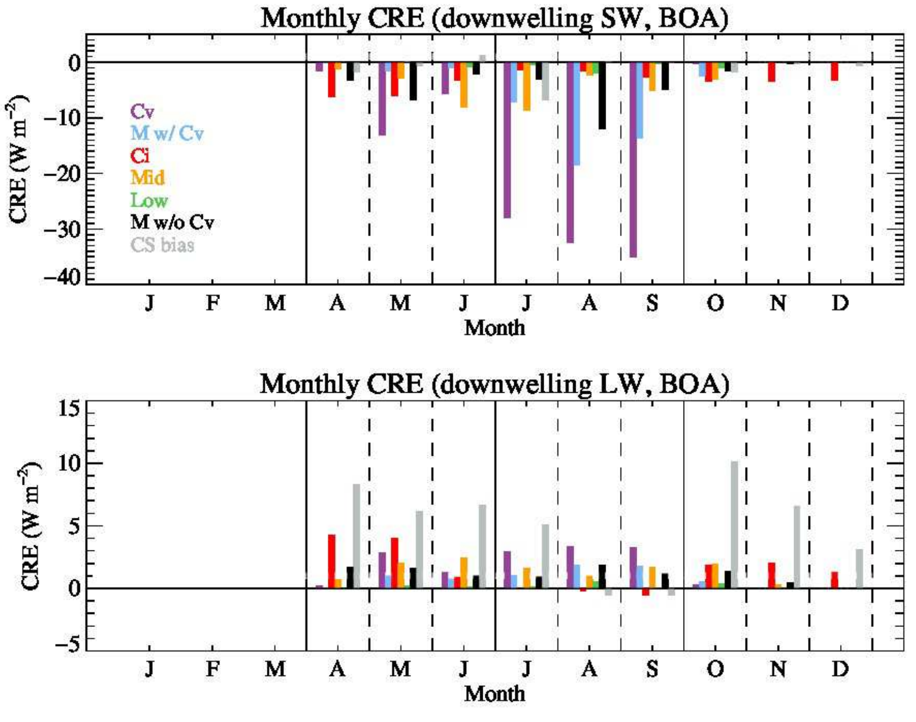
The four cloud types

Example of the different cloud types and aerosol layer diurnal structure



CRE / cloud type (Niamey)

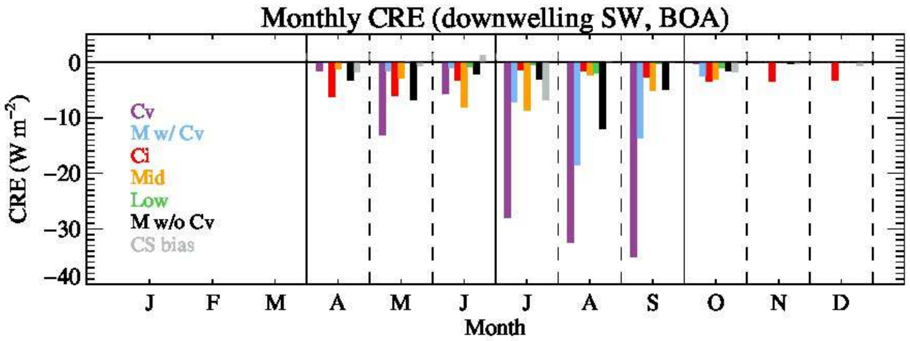
Monthly mean CRE

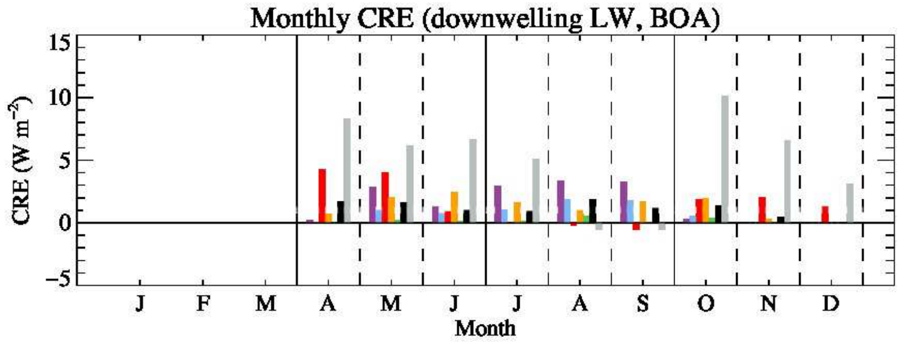


- Cv: larger effect
- Then mid-level and cirrus

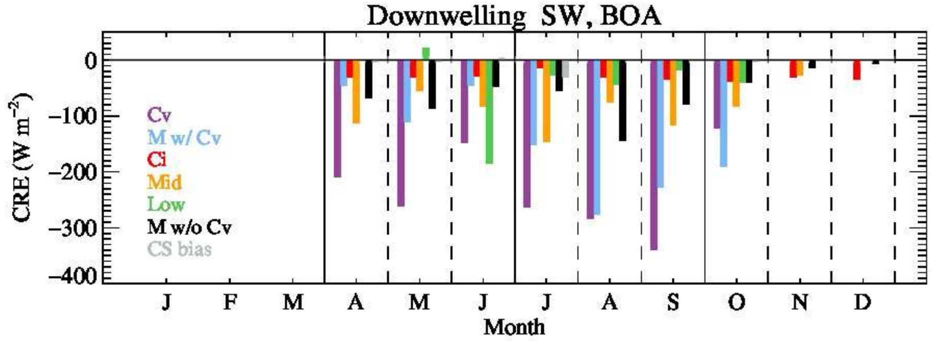
CRE / cloud type (Niamey)

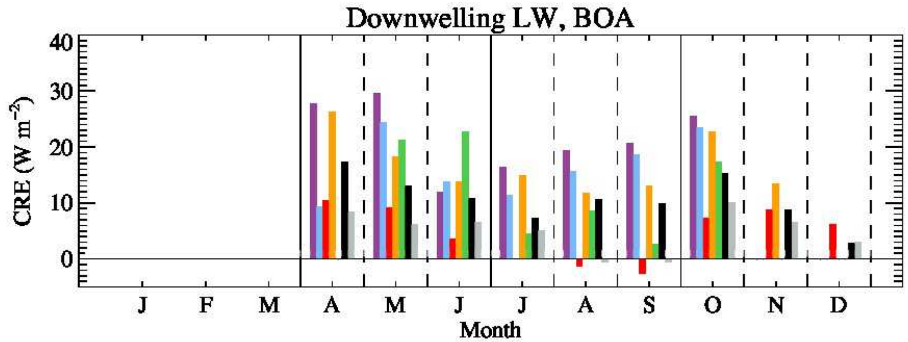
Monthly mean CRE

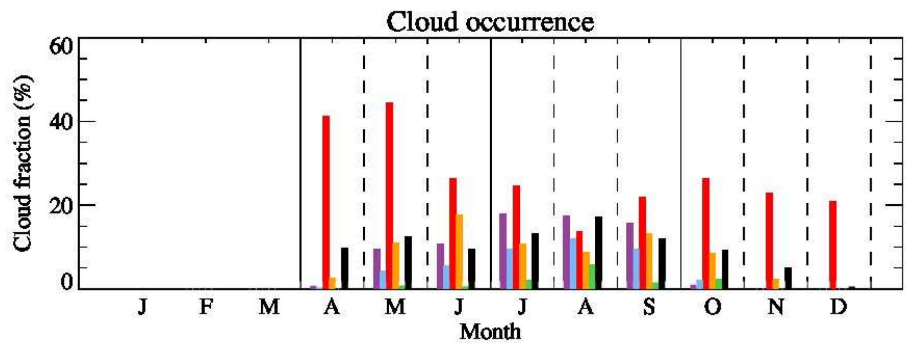




Instantaneous (30-min) CRE



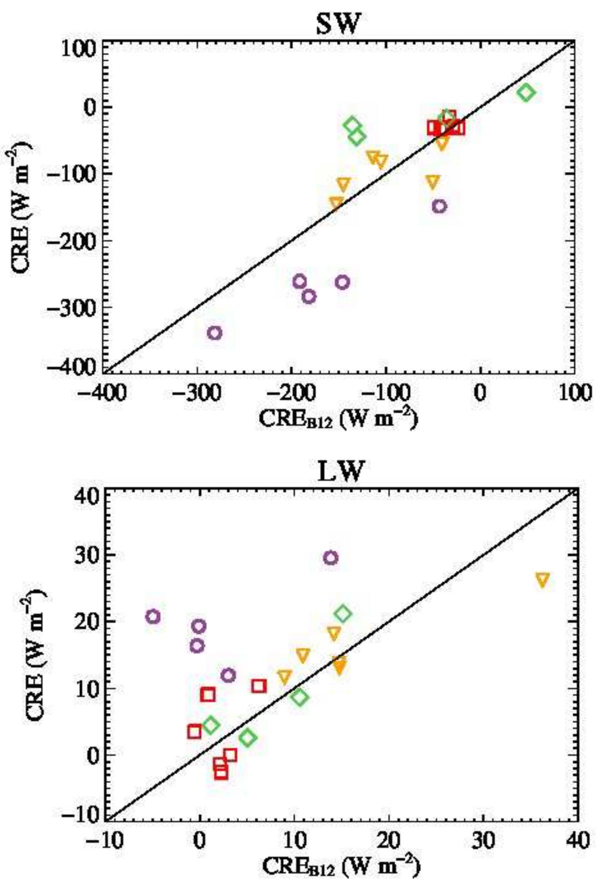




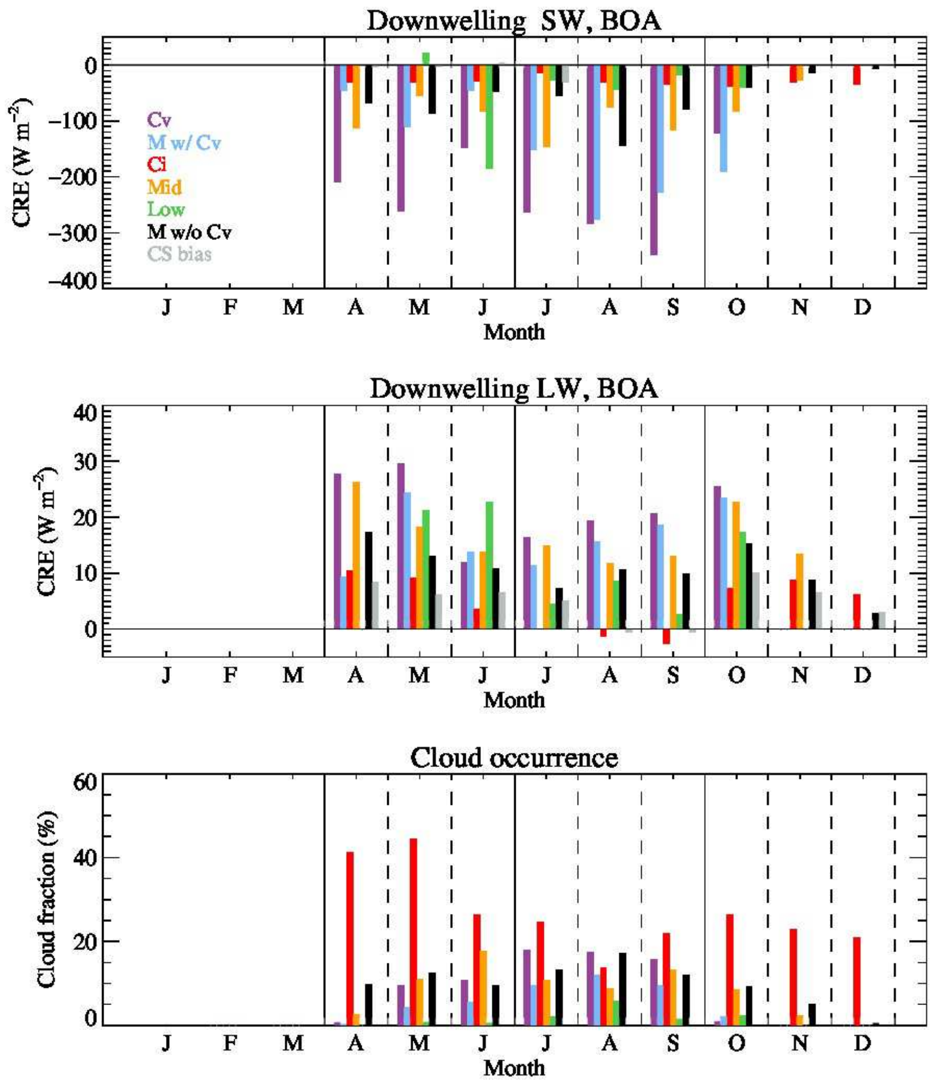
- Cv: larger effect ← largest CRE, moist & wet season
- Then mid-level ← large CRE, moist & wet season
  and cirrus ← large occurrence over the whole year

CRE / cloud type (Niamey)

Comparison with CRE_{B12} of Bouniol et al (2012)



Instantaneous (30-min) CRE



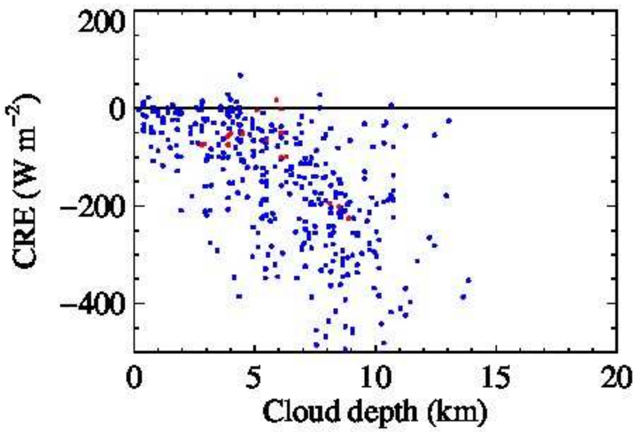
Systematic differences for deep convective clouds Cv
- LW: due to cold anomalies associated with Cv ?
- SW: aerosols ?

CRE=f(depth), anvil cloud

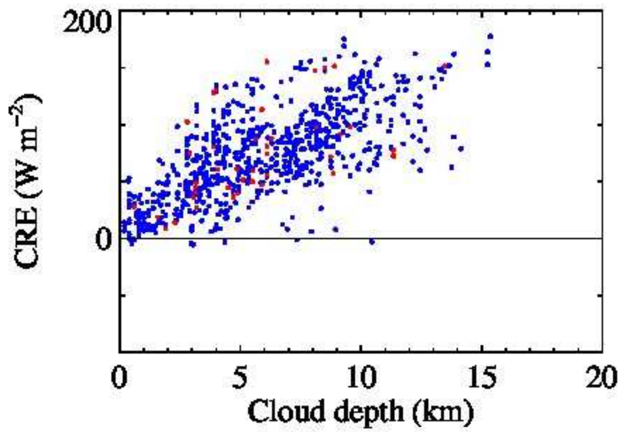
SW

LW

TOA net

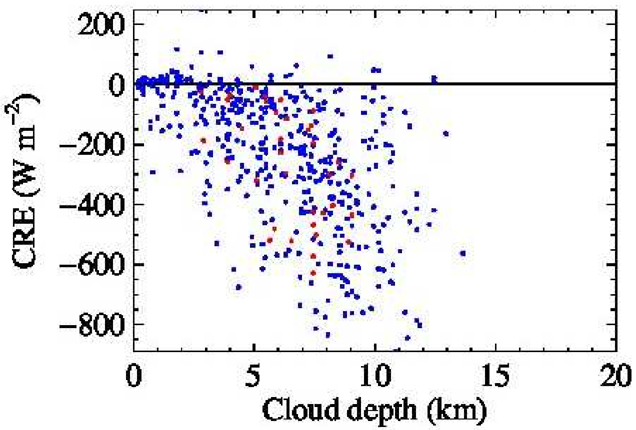


<CRE> = -155 W m^{-2}

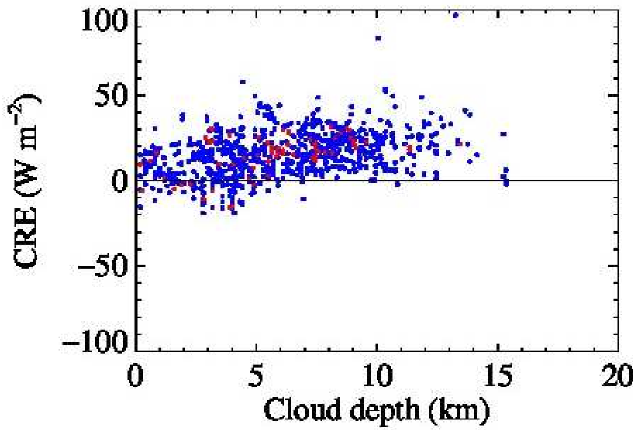


<CRE> = 74 W m^{-2}

Surface downward



<CRE> = -250 W m^{-2}



<CRE> = 15 W m^{-2}

Conclusion and perspective

Use of AMMA, AMF (Niamey), AWS (Nalohou, Agoufou) data and RRTM to diagnose clear- and clean-sky fluxes
→ Clear-sky fluxes in good agreement with measurements whereas some biases specially for dry cases and for BOA fluxes in Nalohou.

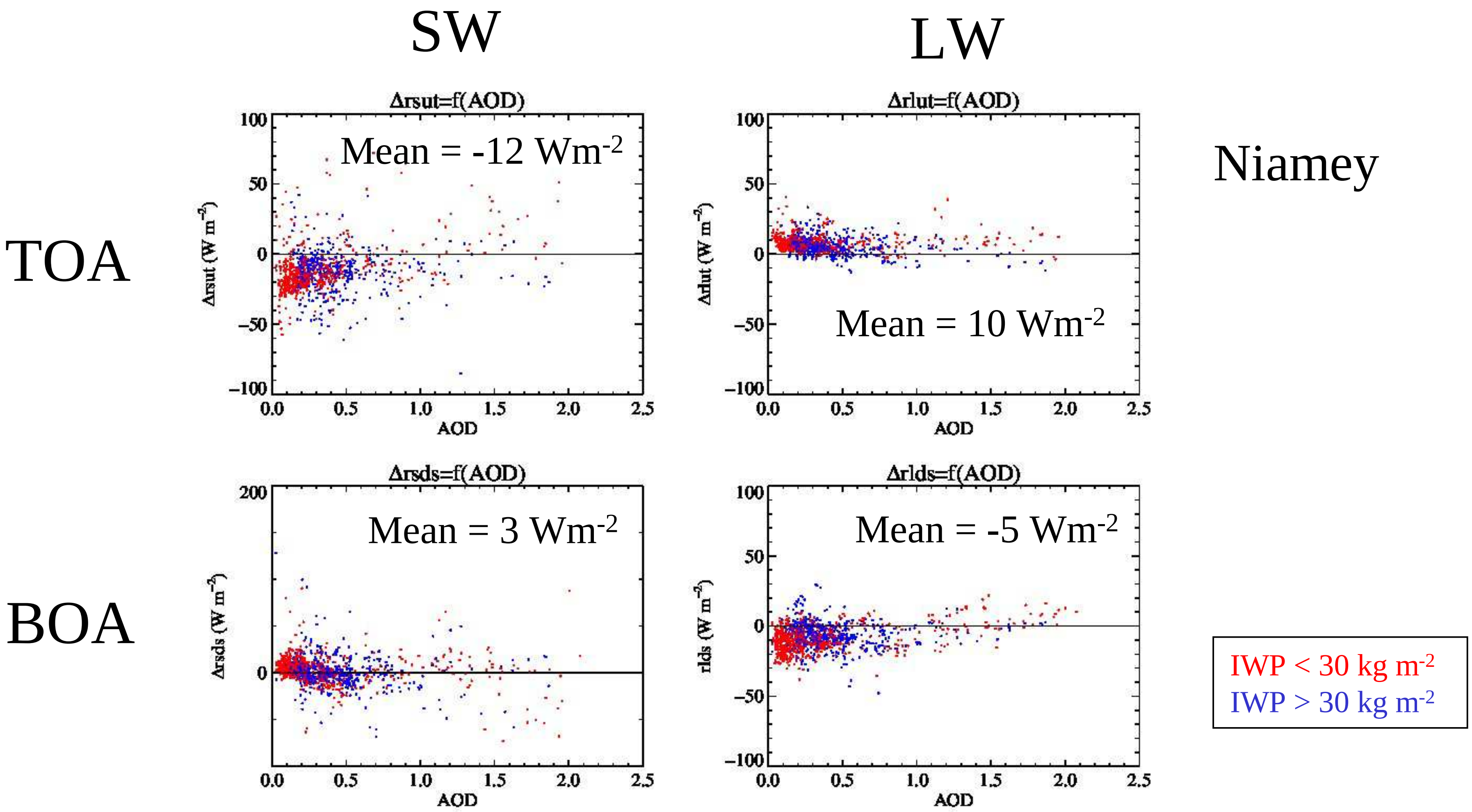
→ Quantitative estimates of BOA, TOA and atmospheric ARE and CRE.
- Annual cycle and meridional variation of CRE and ARE in agreement with West African Monsoon
- Magnitude of ARE+CRE in Niamey differs from previous study (Miller et al., 2012).

→ Contribution of the 4 main cloud types to the CRE
Largest contribution of deep convection / anvil, then mid-level and cirrus.
Results in agreement with Bouniol et al. (2012) (except different magnitude for anvil)

Perspectives:
Analysis of CMIP5 AOGCMs in this region
→ Determine main errors associated with cloud amount, cloud diurnal timing, cloud radiative properties, vertical structure... versus other sources of errors (aerosols, water vapour, temperature).
→ Possibility to adapt such an approach to Cloudsat-Calipso cloud data for sites with no information about the type of cloud in presence.

Reference: Geoffroy, Bouniol, Guichard, 2015: Clouds and aerosols radiative effects over West Africa, seasonal and meridional patterns *to be sudmitted to* J. Appl. Met. Clim.

RRTM-Observation, clear-sky



RRTM-Observation, clear-sky

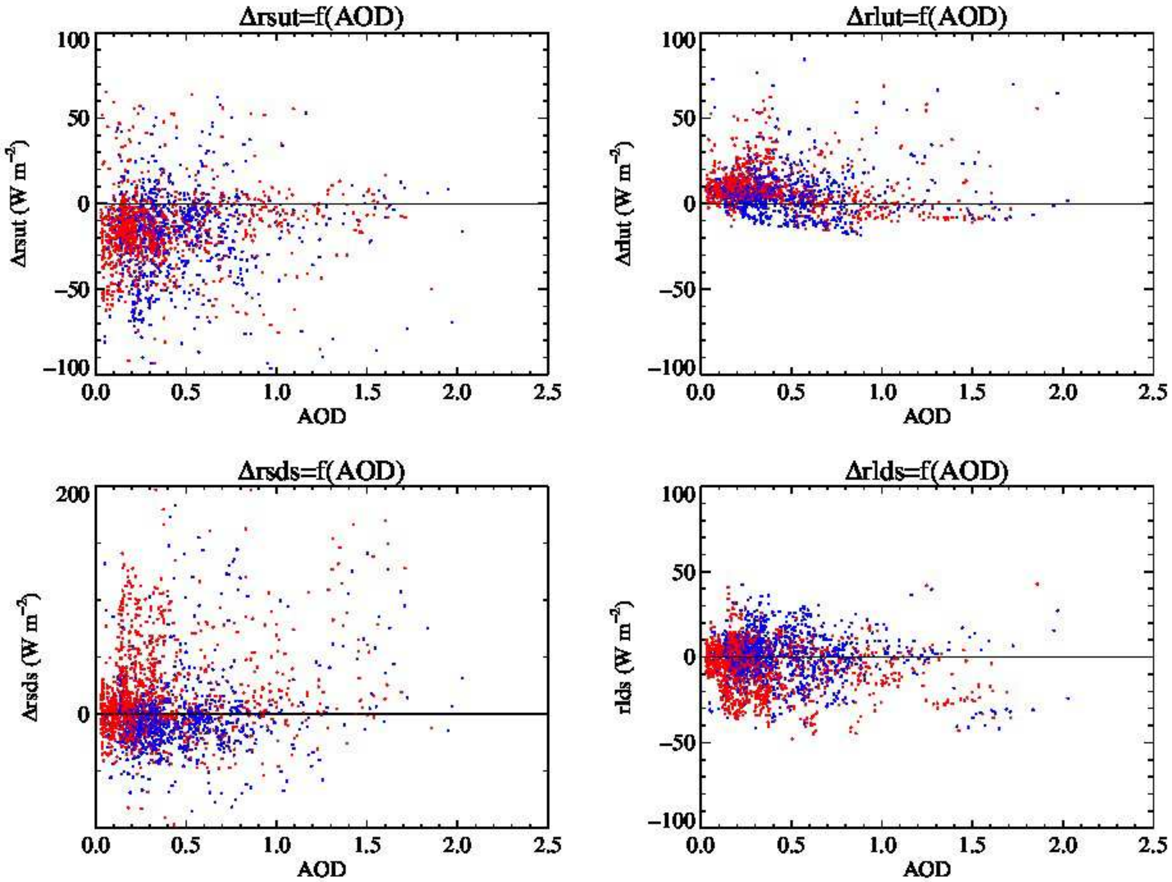
SW

LW

Agoufou

TOA

BOA



IWP < 30 kg m^{-2}

IWP > 30 kg m^{-2}

RRTM-Observation, clear-sky

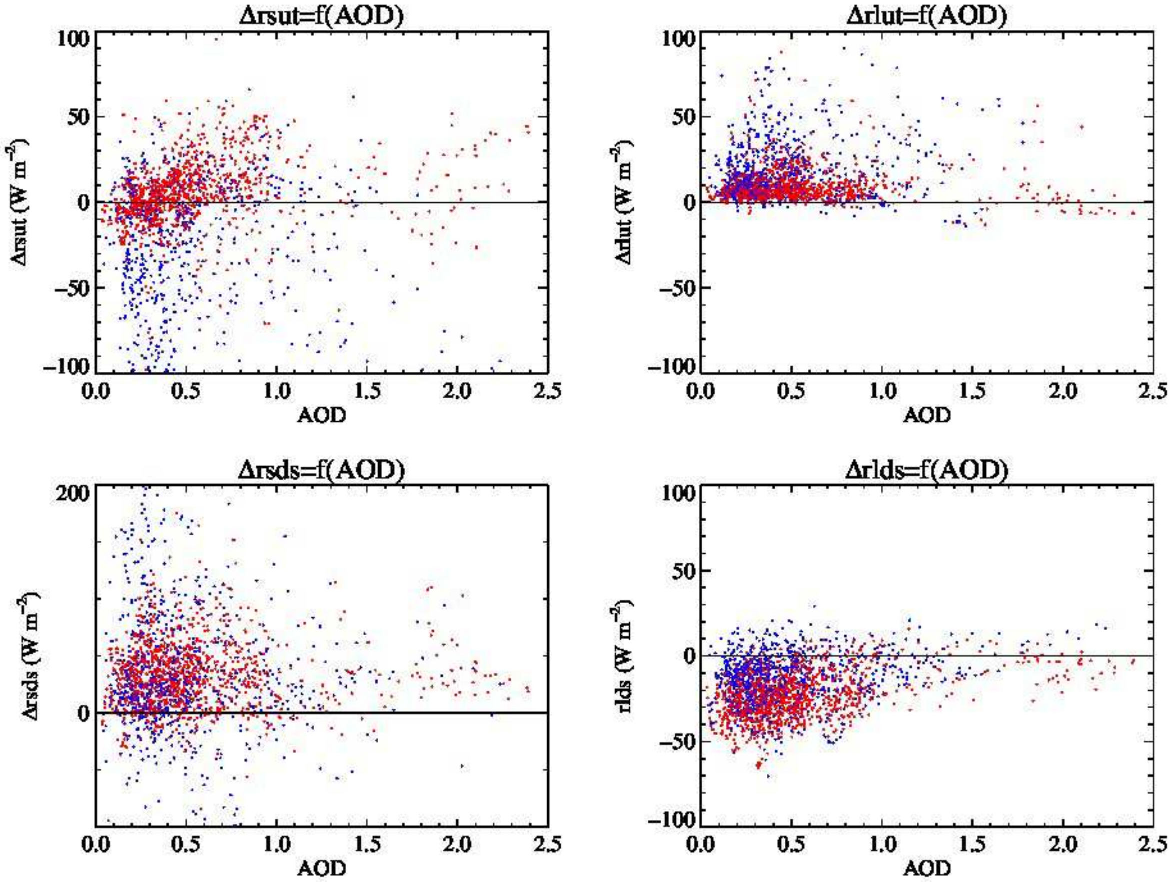
SW

LW

Nalohou

TOA

BOA



IWP < 30 kg m^{-2}

IWP > 30 kg m^{-2}